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An Underwater Sensor Network with DBMS Concept

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Abstract

In this paper is a concept of a technique of sending and receiving message below water. There are several ways of employing such communication but the most common is using hydrophones. Under water communication is difficult due to factors like multi-path propagation, time variations of the channel, small available bandwidth and strong signal attenuation, especially over long ranges. In underwater communication there are low data rates compared to terrestrial communication, since underwater communication uses acoustic waves instead of electromagnetic waves. we present a novel platform for underwater sensor networks to be used for long-term monitoring of coral reefs and fisheries. The sensor network consists of static and mobile underwater sensor nodes. The nodes communicate point-to-point using a novel high-speed optical communication system integrated into the TinyOS stack, and they broadcast using an acoustic protocol integrated in the TinyOS stack. The nodes have a variety of sensing capabilities, including cameras, water temperature, and pres- sure. The mobile nodes can locate and hover above the static nodes for data mining and they can perform network maintenance functions such as deployment, relocation, and recovery. In this paper we describe the hardware and soft- ware architecture of this underwater sensor network. We then describe the optical and acoustic networking protocols and present experimental networking and data collected in a pool, in rivers, and in the ocean. Finally, we describe our experiments with mobility for data mining in this network.

Keywords: Mobile sensor networks, underwater networks, data mining

1. Introduction

The application of wireless sensor networks to the under- water domain has huge potential for monitoring the health of river and marine environments. The oceans alone cover 70% A vector sensor is capable of measuring important non-scalar components of the acoustic field such as the wave velocity, which cannot be obtained by a single scalar pressure sensor. In recent decades, extensive research has been conducted on the theory and design of vector sensors.Many vector sensor signal processing algorithms have been designed . They have been mainly used for underwater target localization and applications of sonar. Earlier underwater acoustic communication systems have been relying on scalar sensors only, which measure the pressure of the acoustic field. Vector sensors measure the scalar and vector components of the acoustic field in a single point in space, therefore can serve as a compact multichannel receiver. This is different from the existing multichannel underwater receivers, which are composed of spatially separated pressure-only sensors, which may result in large-size arrays. In general, there are two types of vector sensors: inertial and gradient. Inertial sensors truly measure the velocity or acceleration by responding to the acoustic medium motion, whereas gradient sensors employ a finite-difference approximation to estimate the gradients of the acoustic field such as velocity and acceleration. Vector sensor communications with three channels the pressure channel p, represented by a straight dashed line, and two pressure-equivalent velocity channels pz and py, shown by curved dashed lines. In this paper we describe an underwater sensor network system that consists of static and mobile sensor nodes (see Figure 1). The system is networked with two communication modalities: ultrasonic and optical. Ultrasonic communications has a long history for underwater applications and is widely used with autonomous underwater vehicles.

It has many similarities to radio: it is a shared medium that sup- ports broadcasting, but the low propagation speed[1] poses a challenge for carrier-sense transmission strategies. Optical communication is capable of much higher data trans- mission rates and the propagation speed is much closer to the speed of light[2] . Unlike ultrasonic and radio communications, optical communication is essentially directional. This dual networking scheme enables many underwater sensor network applications, as it supports low-speed broadcast (e.g. necessary for localization) and high-speed directional data transfer (e.g. for monitoring).

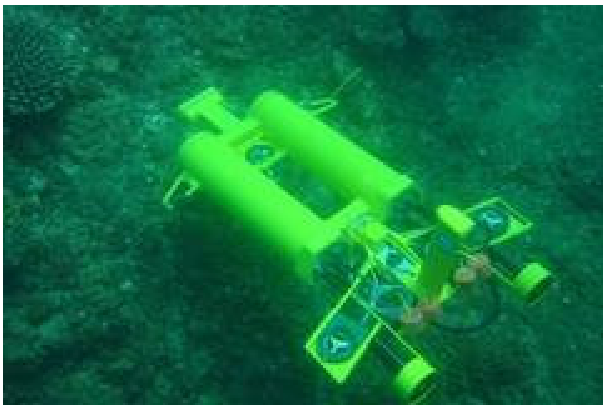
1.1 A Motivating Scenario: Data Collection

The underwater sensor network we propose will facilitate the study of complex underwater systems by regulating and automating data collection. The static sensor nodes enable systematic recording of data. The mobile nodes enable ef- ficient data muling and integration, data delivery to a sur- face base station independent of the physical location of the sensors, and long-term underwater operations of the sensor nodes at fixed locations.
Consider monitoring a large area of the sea floor where the nodes are placed on a 200m grid and cover an area of 10×10km with 50×50 nodes. The total path length to visit all nodes in a raster fashion is 50km which at an effi- cient submarine cruising speed of 0.5m/s would take nearly28 hours of travel time. Further, each node is making a mea- surement every 10 minutes which comprises 4 bytes, givinga total data yield of 24 bytes/hour, or .56 kbytes/day. The 50×50 node network will store 1.37Mbytes/day. If the data from the network is uploaded every 5 days, the accumulated data for each upload will be 6.86Mbytes.The data could be collected in two ways: (1) with an autonomous robot functioning as a data mule using short- range optical communication and (2) using an acoustic com- munication network with node-to-node routing. If the robot visited each node and used the optical transmission devel- oped in this paper (whose data rate is 320 kbytes/sec) 6.86 Mbytes will be uploaded in 21 seconds and the total energy consumed will be 120J. This process will consume only 48mJ from each node.

The energy per bit for acoustic modems is more difficult to obtain. The WHOI modem [2] has a data rate of 220 bits/sec over 5000 m at 10W in transmition mode, or 20mJ/bit. The Aquacomm modem has a data rate of 480bit/s over 200m at 0.45W, or 4.5mJ/bit. Heidemann [11] anticipates 5kbit/s over 500m at 30mW transmit power but does not provide the total power required or show experimental results. For this analysis we will assume 480bit/s at 4.5mJ/bit with a range of 200m. Thus the 6.86 Mbytes of data would require
1.3 days to transmit and the total energy consumed will be 247kJ. Because the modems have only 200m range the data transfer will require multiple hops. If the average path length in the network is 5km this will involve 25 hops, so the total energy consumed will be 6.2MJ. In order to avoid col- lisions in the shared acoustic medium a sophisticated MAC strategy would be required. This strategy may also require a clock synchronization protocol.
The calculations are simplistic and ignore protocol and routing overhead. Nevertheless we can see that the energy consumption by the underwater network is over four orders of magnitude lower with the use of AUV data muling. If we further consider the cost of an optical communications board at \$50/node and the cost of the acoustic modem at
\$3000/node, we argue that the most efficient way for col- lecting data from an underwater sensor network is using a system capable of optical communications with static and mobile nodes, such as the one described in this paper. The mobile nodes will require power to navigate the sensor net- work but they are easily rechargeable. The mobile node will maximize the lifetime and storage utilization for a fixed- configuration underwater sensor network. We have created an asymmmetry in the communications power required, en- abling very low power operations on the nodes that are diffi- cult to access and have fixed energy reserves.
By constrast, the AUV which is mobile and can be recharged at the end of each mission, takes on the energy expensive role.

1.2 Related Work

This work builds on a large body of research in design- ing and building underwater robots [1, 7, 9, 27, 29] and sensor networks [12, 13]. Much of the underwater work to date has been concerned with cabled networks [14] which require sig- nificant engineering and maintenance issues, and acoustic networking [3, 11, 22]. Kilfoyle [18] provides an excellent re- view of underwater acoustic communications. Some of the challenges with designing underwater sensor networks have been articulated in [3]. In [26] a low-power and low-cost optical communications system specifically for the task of submarine to sensor node is described. In [23] an optical sytem for communications and ranging is described.



(A)

Figure 1: Group photo of the underwater sensor nodes.. (a) a mobile node (Starbug AUV)

(b)

Figure 1: Group photo of the underwater sensor nodes.. (a) a mobile node (Starbug AUV). (a) the static sensor nodes (Aquaflecks) and a mobile node (Amour AUV)
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use of robots and sensor networks has been previously men- tioned [4, 6, 26]. Recent results on using mobility in sensor networks to increase the network coverage and reduce power consumption suggest that data muling is an effective means of networking. In [24], Jain et al. proposed to use mobile mules, such as buses and animals to collect data by moving across a sparsely deployed sensor network. Communications is enabled only when the sensors and the mobile mules are in close proximity. Transmitting data over these shorter distances reduces the power consumption on each sensor. In [10] a study on how mobility can be used to increase the capacity of ad-hoc wireless network is presented. In [5, 21] a study that analyzes performance in terms of an integrated measure of capacity, delay, and mobility is presented. In [28] an analysis of power consumption in sensor networks is pre- sented.

2. THE HARDWARE INFRASTRUCTURE

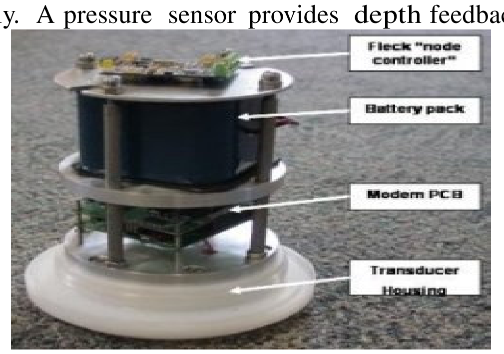
Our research has two critical hardware elements: the static underwater sensor nodes, and the autonomous underwater vehicles (AUVs) which provide communications, mobility and a means of sensor node deployment and recovery. In our work we employed two AUVs: Starbug and Amour.

2.1 Underwater Sensor Node Aquafleck

We have built 20 underwater sensor nodes called Aquaflecks (see Figure 2). Each node is build around a CPU unit de- veloped by CSIRO called a Fleck [25], based on the AT- mega128 processor, with 128kbyte of program flash mem- ory, 4kbyte of RAM, and 512kbyte of flash memory for data logging/storage. The Fleck is interfaced to a special opti- cal communications board through 2 digital IO pins. One of these pins is used to turn an LED on or off, while the other is used to sense the output from a matched photo- diode. All the analog electronics (e.g., amplifiers etc) are on the interface board. The Fleck is also interfaced with a sensor board. The boards are connected in a stack using stack-through connectors.the underwater sensor node is contained in a yellow wa- tertight Otter box that measures $170 \times 100 \times 90$ mm and has been modified to incorporate the sensing and communica- tion hardware. The Otter box is guaranteed to be water- tight up to a depth of 30 meters. Each box has a high speed optical communication module that uses 532nm light, and is capable of a range of 2.2m/8m[3] , within a cone of 30 degrees and a maximum data rate of 320kbits/s. Additionally, there is a acoustic communication module using 30kHz FSK mod- ulation with a range of 20m omnidirectional, and a data rate of 50bit/s. The same module is also used for ranging[4] . For sensing, each node has a pressure sensor, temperature sen- sor, and a CMUCam camera capable of color pictures with a 255×143 resolution. The top side of the box contains a 170 mm rod with an LED beacon. The rod can be used by an AUV to locate the box, dock, and pick it up. Future versions will contain a XENON flash tube for increasing the distance for reliable node location to about 20 meters. The sensor node is powered by 3 alkaline C cells.

2.2 Amour AUV

In this project Amour is a mobile node AUV used to dock and transport the Aquafleck nodes. Amour can also locate an underwater sensor node and hover above it for data mul- ing. Figure 1(Top) shows Amour next to Aquaflecks.
The robot’s body consists of an acrylic tube that is 48.26 cm long and 15.24 cm in diameter. It has four external thrusters with a maximum power of 150W and a maximum static thrust of 35 N each. The robot is statically balanced in an upright position. Two of its thrusters are aligned verti- cally. A pressure sensor provides depth feedback. The other



(a)

Figure 2: The underwater sensor node. (a) top of the node containing the sensors and the docking rod

(b) inside showing circuitry.

two thrusters are positioned horizontally to provide forward- backward movement in the horizontal plane as well as rota- tion. A magnetic compass is used for orientation feedback and enables patterns of navigation, for example movement along a grid and spiral search. The power is provided by a 140Wh lithium polymer battery. The main processor is a 8-bit microcontroller with 64kbyte of program memory and 2kbyte of RAM.

The bottom cap of the robot has a cone shaped cavity, designed for maximum mechanical reliabil- ity in docking and for optical communication. The robot can dock with sensor nodes in order to pick them up and transport them to a new location. This operation enables autonomous network deployment, reconfiguration, and re- trieval. The docking system is general in that the robot can dock with any mate whose docking element is a 15.24 cm long rod of 1 cm diameter. The bottom cap also contains 4 light sensors pointing in complementary directions. The sensors can determine the direction toward a high frequency modulated light source (an LED) from up to 8 meters in clear water. A latching mechanism can hold the docked ele- ment with up to 200 N of force. The robot includes the same optical communication units as the static sensor nodes de- scribed in Section 2.1. Most of the electronics inside the robot, including the batteries, are placed in small Otter wa- tertight cases. Recharging the batteries or reprogramming the robot can be done through watertight top cap connec- tors, without opening the main body.

2.3 Starbug AUV

In this work Starbug is a mobile node used to locate the Aquafleck nodes by vision, to hover above Aquaflecks for data muling, and to dock with Amour in order to provide visual control feedback for long range navigation. This form of coordinated control is the subject of another paper.
Starbug is a hybrid AUV designed to optimize endurance, manoeuvrability and functionality [7]. Endurance is best achieved with a streamlined torpedo style vehicle, however, this requires the vehicle to have longitudinal motion to ob- tain any control authority. Manoeuvrability is best achieved with the well actuated "crate" style vehicles typical of most research platforms. These generally have control author- ity in multiple directions to allow station keeping although they are power hungry and consequently usually tethered. Both these style of vehicles have limited functionality away from research purposes. The "Starbug" vehicle is a hybrid of these two concepts with extra design features added to in-crease the functionality of the platform through provisions for manipulators and scientific payloads.The key performance specifications for Starbug are: mass
26kg, length 1.2m (folding to 0.8m for transport), maxi- mum forward thrust 20N, maximum speed 1.5m/s, Speed for maximum range 0.7m/s, hotel load 1.1 Amps, and bat- tery capacity 6.4Ah (4x12V sealed lead acid batteries). The vehicle is fully actuated with six thrusters providing for- ward, lateral and vertical translations as well as yaw, roll and pitch rotations. Vehicle control software effectively de- couples the thruster force and allows independent control of vehicle force and moment in 6DOF. All the thrusters are daisychained on a CANBus control network, allowing for a single hull penetration. Internal sensors such as pressure and IMU are also on the CANbus.
Starbug has two stereo vision heads. One looking down- ward for sea-floor altitude and speed estimatation as well as mapping, and the other looking forward for obstacle avoid- ance. The camera

pairs have a baseline of 70mm. This al- lows an effective height resolution in the range 0.2 to 1.7m. All cameras are tightly synchronized and line multiplexed into PAL format composite video signal. A 3W white LED located in each camera housing provides additional scene lighting. The onboard computer is a PC/104 stack with a Crusoe processor running Linux. An Aquacomm acoustic communications link with a bandwidth of 100bps and range of 200m is also fitted.

3. NETWORKING

Sensor network communication on land is primarily radio- based, due to the relatively low power needed to transmit radio messages and the basically omnidirectional nature of radio propagation. Unfortunately, the majority of the elec- tromagnetic spectrum is significantly attenuated by saltwa- ter, rendering radio communication useless for this appli- cation. The exception is in the visible light portion of the spectrum that is less attenuated, especially in the the fre- quency of blue-green light. The primary advantage of optical communication is the higher theoretical data rate due to the higher frequency signal, while the disadvantages are range and line-of-sight operation.
The other obvious approach for underwater communica- tion is sound. This has been used extensively for localization (SONAR) and short range communication (the "gertrude" or UQC underwater telephone). While acoustic communi- cation can be used for much longer range communication than optical it also suffers from attenuation, with higher frequencies being attenuated more than lower frequency sig- nals. Thus a tradeoff is required between communication

(a)

Figure3(a)Starbug in Moreton Bay, Brisbane

(b)

(b) Starbug in the pool. (c) Image of Aquafleck at bottom of the pool, as taken from the Starbug AUV and used for node identification and relative positioning.

6. CONCLUSIONS

In this paper we reported on a first prototype for an an underwater sensor network we developed, built, and used. We described the hardware, the networking infrastructure, and our experiments with data collection and retrieval.
This work demonstrates that sensor networks are feasible underwater and that data muling provides an effective way to collect, store, and retrieve large volumes of data overlong periods of time. We argue that data muling provides a significant power advantage over an acoustic communication network with multihop routing. Our work shows the benefits of creating underwater sys- tems that

have a mix of static and mobile nodes networked together in dual ways, as a combination of acoustic commu- nication for low data rate broadcast and optical communica-tion for high data rate point-to-point communication. The static sensor nodes enable systematic recording of data. The mobile nodes enable efficient data muling and integration, data delivery to a surface base station independent of the physical location of the sensors, and long-term underwater operations of the sensor nodes at fixed locations.

The contributions of this paper include several algorithms for controlling and networking the static and mobile nodes. These algorithms have been instantiated to the specific hard- ware we developed. However, the algorithms for docking and navigation can be instatiated to other hardware systems with different architecture but similar capabilities. Simi- larly, the algorithms for optical data encoding and acoustic data encoding and medium access are generic and can be used in future generations of underwater sensors. Data collection, storage and retrieval in underwater en- vironments is a rich application domain with many tech- nical challenges left to be resolved. We have learned sev- eral lessons during the development of this work. Hardware and software reliability are extremely important. Mobil- ity provides an effective and highly power-efficient means for collecting data in sensor networks, for network program- ming, and more generally speaking for networking the sys- tem. However, controlling the mobile nodes in the presence of currents remains challenging and affects the reliability of hovering for data transfers. Above all, underwater sensor networks promise many exciting applications and opportu- nities to collaborate with marine biologists to enrich our understanding of the underwater world.

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7. REFERENCES

[1] Autonomous Ocean Sampling Network (AOSN)II, collaborative project.
http://www.princeton.edu/dcsl/aosn/.

[2] Whoi modem:
http://acomms.whoi.edu/micromodem/.

[3] Akyiditz, I., Pompli, D., and Melodia, T.
Underwater sensor networks: Research challenges.
Ad-hoc Networks (2005 (to appear)).

[4] Akyildiz, I. F., Pompili, D., and Melodia, T.
Challenges for efficient communication in underwater acoustic sensor networks. ACM Sigbed Review 1, 2 (july 2004).

[5] Bansal, N., and Liu, Z. Capacity, delay and mobility in wireless ad-hoc networks. In INFOCOM (San Francisco, CA, April 2003).

[6] Bokser, V., Oberg, C., Sukhatme, G., and Requicha, A. A small submarine robot for experiments in underwater sensor networks. In IFAC - International Federation of Automatic Control Symposium on Intelligent Autonomous Vehicles
(2004).

[7] Dunbabin, M., Roberts, J., Usher, K., Winstanley, G., and Corke, P. A hybrid auv design for shallow water reef navigation. In Proceedings of the 2005 International Conference on Robotics and Automation (Barcelona, Apr. 2005), pp. 2117–2122.

[8] Dunbabin, M., Usher, K., and Corke, P. Visual motion estimation for an autonomous underwater reef monitoring robot. In Proc. International Conference on Field & Service Robotics (Port Douglas, 2005),

pp. 57–68.
[9] Fiorelli, E., Leonard, N. E., Bhatta, P., Paley, D., Bachmayer, R., and Fratantoni, D. M.
Multi-AUV control and adaptive sampling in Monterey Bay. In Proceedings of the IEEE Autonomous Underwater Vehicles: Workshop on Multiple AUV Operations (Sebasco, ME, USA, June 2004).
[10] Grossglauser, M., and Vetterli, M. Locating nodes with ease: Mobility diffusion of last encounters in ad hoc networks. In INFOCOM (San Francisco, CA, April 2003).
[11] Heidemann, J., Li, Y., Syed, A., Wills, J., and Ye, W. Underwater sensor networking: Research challenges and potential applications. Tech. Rep.
ISI-TR-2005-603, USC/Information Sciences Institute, July 2005.
[12] Hill, J., Bounadonna, P., and Culler, D. Active message communication for tiny network sensors. In INFOCOM (2001).
[13] Hill, J., Szewczyk, R., Woo, A., Hollar, S., Culler, D., and Pister, K. System architecture directions for network sensors. In ASPLOS (2000).
[14] Howe, B. M., McGinnis, T., and Kirkham, H.
Sensor Networks for Cabled Ccean Observatories. EGS - AGU - EUG Joint Assembly, Abstracts from the meeting held in Nice, France, 6 - 11 April 2003, abstract #12598 (Apr. 2003), 12598–+.
[15] Jain, S., Shah, R., Brunette, W., Borriello, G., and Roy, S. Exploring mobility for energy efficient data collection in sensor networks. ACM/Kluwer Mobile Networks and Applications Journal to appear (2005), roc. of 2004 WiOpt 2004.